

SAFETY RELIABILITY OF STATIONARY AND NON-STATIONARY MACHINERY

Joanna TABOR

Abstract: This Chapter contains a review of safety reliability for stationary and non-stationary machinery, based upon analysis of incidents that deviated from normal faultless operation and caused accidents at work in years 2005 - 2012. As a result of our research, we identified some basic areas of failure – deviations while operating the analysed machinery groups in the area of the human factor and in the area of technical objects. Higher failure rate was observed in the area of the human factor, whereas lower failure rate – in the area of technical objects.

Key words: operation, reliability, safety reliability, accidents at work, machinery.

1. Introduction

Accidents at work constitute the key issue in international, European and national politics in the area of safety and health protection in places of work, as they can not only lead to loss of life, health and the ability to work, but can also cause high economic losses that reach from 2.6 to 3.8% of their GDP (as per EASHW data) in European Union countries. In line with the Tool Directive of 16 September 2009 *concerning the minimum safety and health requirements for the use of work equipment by workers at work*, safety improvements, hygiene and health protection in a place of work are objectives that should not be subordinated to economic considerations only [1].

Research works conducted in many countries indicate that approx. 25% of all accidents at work are connected with using machinery, whereas a significant group of reasons for these accidents includes inaccurate quality of a material factor – machinery or equipment, which manifests itself in design defects, inappropriate technical or ergonomic solutions, inaccurate workmanship, as well as in material defects [2]. Pursuant to the Machinery Directive of 17 May 2006 *upon machines*, social costs of a high number of accidents caused directly by using machines can be cut down by designing and building machines that are safe by definition due to their proper installation and maintenance [3].

2. Safety reliability

Safety in work processes is influenced by two groups of factors: the first one is connected with non-failure, and the second one with hazards occurring as a result of occurrence of undesired events that are called “inefficiencies”, which can be material or arbitrary in nature.

Reliability is a comprehensive property of an object, which characterises its ability to perform determined functions in determined conditions and in a determined period of time with no inefficiencies, whereas, the notion of an “object” [4] should be understood as any technical object: machine, device, apparatus, installation, building, technical object’s

subassembly, subassembly's element, software, as well as the "man-machine" system, and a single man or an organised team of people who perform some determined tasks.

Depending upon the intended use of the object and conditions of its operation (usage), reliability may comprise such features as: durability, availability, non-damageability, operability, repairability, storeability, faultlessness, control, biological reliability, environmental non-hazardousness, etc [5].

Reliability may be assessed quantitatively and qualitatively. Quantitatively, the object's reliability is assessed using non-failure indicators that are selected and appointed taking into account the object's properties that require qualitative evaluation, and using manners and conditions of its operation. However, it should be remembered that reliability and its indicators are relative in nature. Table 1 contains classification of reliability of objects (except for a human being).

Tab.1. Classification of reliability of objects (or systems)

Reliability	Definition
Usability reliability	Expresses a decision-maker's (operator's) trust that the object (system) will make it possible for a required task to be successfully completed.
Maintenance reliability	Expresses a decision-maker's (operator's) trust that the object (system) may be subjected to maintenance (to restore its aptitude) in determined conditions and in a determined period of time.
Safety reliability	Expresses a decision-maker's (operator's) trust that the object (or system) will perform a determined operational task without any hazard for people, itself and its surroundings.
Administrative reliability	Expresses a decision-maker's (operator's) trust that the object (system) will perform determined operational task without violating applicable standards, regulations, commands and prohibitions.
Economic reliability	Expresses a decision-maker's (operator's) trust that the object (or system) will perform a determined operational task with some economic profit.

Source: based upon L. Będkowski, T. Dąbrowski: Podstawy eksploatacji. Część II. Podstawy niezawodności eksploatacyjnej. Wydaw. WAT, Warszawa 2006 [6].

In case of human being's (operator's, decision-maker's) reliability, we must take into account his specific controlling role that he plays in each "man – machine – environment" system. Human inefficiencies (errors), whether conscious or unconscious, exert a predominating influence upon the reliability of the system as a whole. It has been reported that human errors in the "man – machine – environment" system are responsible for 60 to 90% of all failures and disasters [4].

Safety reliability expresses decision-maker's (operator's) trust that an object (a machine, device or system) will perform a determined operational (usage and maintenance) function without any hazard for people, for the object itself and its surroundings [6]. Such trust may be based upon experience from observation of objects of the same type that are functioning in the same or close operational conditions or theoretical analysis and results of simulations of operational processes.

On the other hand, "safetiness" means the object's feature that conditions its safe existence and functioning, i.e. it is a condition in which the object poses no hazard to human (not only operator's) health or life, poses no hazard to itself, and poses no hazard to other objects and the environment around it.

“Safetiness” may be shaped at the object’s designing, production and operation (usage and maintenance) stages. Table 2 lists some basic methods of shaping reliability of machines as objects, which also exert some impact upon safetiness reliability.

Tab.2. Methods of shaping reliability of machines

Pre-operational methods (design and technological)	Operational methods
<ul style="list-style-type: none"> - dynamic optimisation of the system, - making use of higher quality elements, - making use of (parametrical, strength, structural, functional) reserves, - automated control, - automated start-up, - rational installation, - improved control capabilities, - improved repairability, - using high-readiness elements, and improved quality of process documentation. 	<ul style="list-style-type: none"> - stability of operational conditions, - thermal stability, - optimised loads, - predicting damages, - regeneration, - introducing operational excess levels.

Source: based upon S. Legutko, *Eksploatacja maszyn*, Wydaw. Politechniki Poznańskiej, Poznań 2007 [7].

3. Own research methodology

The objective of the research we have conducted was to analyse safety reliability for selected machinery groups. We assumed that safety failure may be proved by events that deviate from normal faultless operation and result in accidents. In the area of incidents of this type, two machinery groups were compared: portable or moving (non-stationary) machinery – groups from 09.01 to 09.99, and stationary machinery – groups from 10.01 to 10.99. Thus:

- we analysed average shares of incidents that deviated from normal faultless operation, for stationary and non-stationary machinery,
- we compared structures of shares of incidents that deviated from normal faultless operation, for stationary and non-stationary machinery in successive analysed years, and
- we identified tendencies in the area of variations in shares of particular incidents that deviated from normal faultless operation, for stationary and non-stationary machinery, in years 2005-2012.

In our work, we used statistical data for years 2005 – 2012 [8], as gathered by the Central Statistical Office based upon the Statistical Accident Chart, whose manners of compiling and submitting were regulated in relative regulations *upon Statistical Accident Chart at work* [9, 10]. The Statistical Accident Chart form is designed in such a way as to make it possible to indicate a single incident that constitutes deviation from normal faultless operation.

4. Characteristics of incidents that deviate from normal faultless operation, and result in accidents at work

An incident that constitutes a deviation from normal faultless operation is an event that is non-compliant with the proper course of the work process, which, in consequence, results

in accident. Classification of deviations from normal faultless operation, in compliance with clarifications as attached to the Statistical Accident Chart, is presented in Table 3.

Tab.3. Classification of deviations from normal faultless operation as used in the Statistical Accident Chart

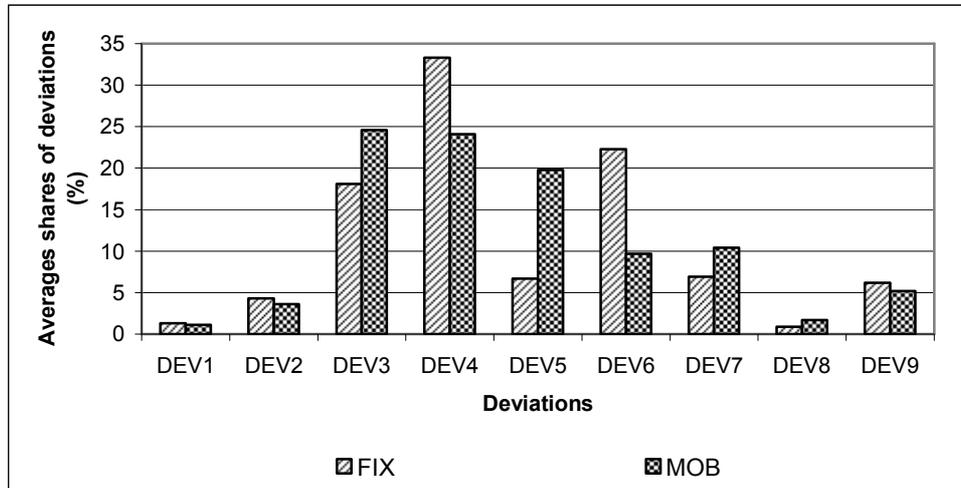
Group	Description of groups
DEV1	Deviation due to electrical problems, explosion, fire
DEV2	Deviation by overflow, overturn, leak, flow, vaporization, emission
DEV3	Breakage, bursting, splitting, fall, collapse of Material Agent
DEV4	Loss of control of machine, means of transport or handling equipment, handheld tool, object
DEV5	Slipping, stumbling, fall of persons
DEV6	Body movement without any physical stress
DEV7	Body movement under or with physical stress
DEV8	Shock, fright, violence, aggression, threat, presence
DEV9	Other deviations

Source: based upon Statistical Accident Chart at work [9, 10].

Group 1 of incidents covered electricity-related deviations leading to indirect or direct contact, explosion, fire, ignition, etc. Group 2 comprised: falling out, spilling, discharge of solid substances, overflow, leak, flow, spraying liquids, emissions of vapours, gases, dust, smoke, particles, etc. Group 3 contained: damage to a material at its connection or seam area, rupture with arising chippings, breaking of a material factor, victim being hit by a falling material factor, victim being pulled downstairs, victim falling at the same level, etc. Group 4 included: loss of control over the machine or the material being processed, loss of control over the means of transport or the moving equipment being operated, over a tool (including a mechanised one), loss of control over an object, etc. Group 5 covered: a person falling from height onto a lower level, slipping, falling at the same level, etc. Group 6 included movement of the body without physical effort generally leading to external injuries, such as: walking onto a sharp object, kneeling, sitting down, leaning against, a person being seized or thrown away, uncoordinated inappropriate movements, etc. Group 7 covered: movement of the body connected with physical effort, most frequently leading to an internal injury, such as: raising, pushing, pulling, bending, turning, wrong foot step, etc. Finally, group 8 comprised such events as: shock, fear, violence, attack (both on the part of employees and visitors), aggression, bumping into someone, presence in the hazardous area, etc.

5. Safety reliability analysis using deviations from normal faultless operation

Figure 1 lists average share of incidents that deviate from normal faultless operation while operating stationary and non-stationary machinery, for years 2005-2012.



DEV1- Deviation due to electrical problems, explosion, fire, DEV2- Deviation by overflow, overturn, leak, flow, vaporization, emission, DEV3- Breakage, bursting, splitting, fall, collapse of Material Agent, DEV4- Loss of control of machine, means of transport or handling equipment, handheld tool, object, DEV5- Slipping, stumbling, fall of persons, DEV6- Body movement without any physical stress, DEV7- Body movement under or with physical stress, DEV8- Shock, fright, violence, aggression, threat, presence, DEV9- Other deviations

Fig.1. Average share of incidents that deviate from normal faultless operation for stationary machinery (FIX) and non-stationary machinery (MOB) in years 2005-2012

Source: our own work based upon annual GUS reports concerning accidents at work [8].

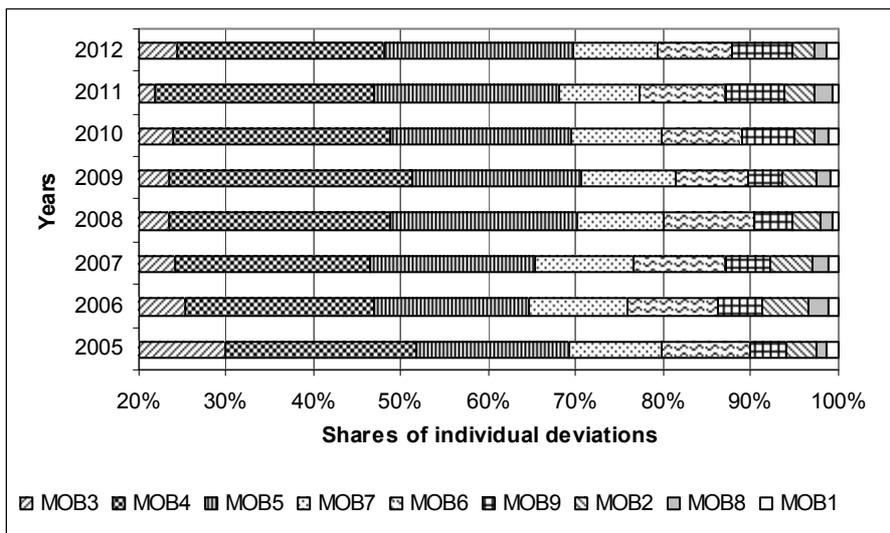
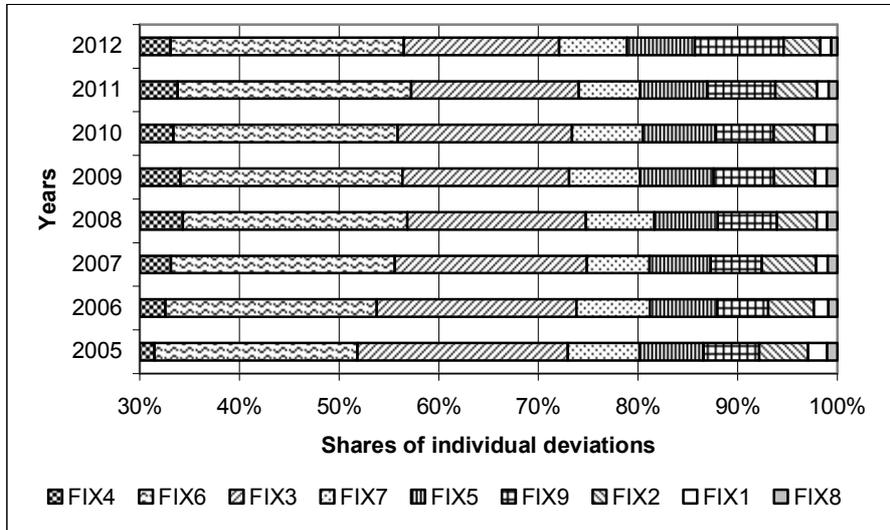
Analysing Figure 1, it can be observed that in years 2005-2012:

- the highest share of incidents that deviated from normal faultless operation, for stationary machinery, pertained to loss of control over the machine, load or tool (OD4 – 33.3%),
- on the other hand, the highest share of incidents that deviate from normal faultless operation, for non-stationary machinery, covered damage, rupture, cracking, falling, breaking of a material factor (OD3 – 24.6%).

At the same time, comparison of shares of deviations for stationary and non-stationary machinery suggests that:

- in case of stationary machinery, higher shares pertained to loss of control over the machine, load or tool (OD4) and movement of the body without physical effort (OD6),
- on the other hand, in case of non-stationary machinery higher shares covered: damage, rupture, cracking, falling, breaking of a material factor (OD3), slipping, stumbling, falling of a person (OD5), and movement of the body connected with physical effort (OD7).

Furthermore, in years 2005-2012, significant variations were observed in the share of incidents of incidents that deviated from normal faultless operation in case of both stationary and non-stationary machinery – Figure 2.



DEV1- Deviation due to electrical problems, explosion, fire, DEV2- Deviation by overflow, overturn, leak, flow, vaporization, emission, DEV3- Breakage, bursting, splitting, fall, collapse of Material Agent, DEV4- Loss of control of machine, means of transport or handling equipment, handheld tool, object, DEV5- Slipping, stumbling, fall of persons, DEV6- Body movement without any physical stress, DEV7- Body movement under or with physical stress, DEV8- Shock, fright, violence, aggression, threat, presence, DEV9- Other deviations

Fig.2. Structure of shares of incidents that deviated from normal faultless operation for stationary machinery (FIX) and non-stationary machinery (MOB) in years 2005-2012
Source: our own work based upon annual GUS reports concerning accidents at work [8].

By comparing the structure of shares of incidents that deviated from normal faultless operation, the following observations were made for stationary machinery made in the successive analysed years:

- increased share – in case of incidents connected with loss of control over the machine, load or tool (OD4), movement of the body without physical effort (OD6), and slipping, stumbling, falling of a person (OD5),
- on the other hand, lower share – in case of incidents connected with damage, rupture, cracking, breaking of a material factor (OD3), with movement of the body involving physical effort (OD7) and with discharge leak or emission of harmful substances (OD2).
- At the same time, the following observations were made for non-stationary machinery:
 - increased share – in case of incidents connected with loss of control over the machine, load or tool (OD4) and with slipping, stumbling, falling of a person (OD5),
 - on the other hand, lower share – in case of incidents connected with damage, rupture, cracking, breaking of a material factor (OD3), with movement of the body involving physical effort (OD7), with movement of the body without physical effort (OD6), and with discharge, leak or emission of harmful substances (OD2).

In Figures 3, 4, 5 and 6, tendencies were identified in variations in shares of incidents that deviated from normal faultless operation, for stationary machinery (FIX) and for non-stationary machinery (MOB), in years 2005 - 2012.

6. Summary

The objective of research as presented in this Chapter was to analyse safety reliability for stationary and non-stationary machinery, using statistical data concerning incidents that deviated from normal faultless operation in the work process, and therefore resulting in accidents.

By comparing average shares of incidents that deviated from normal faultless operation it was noted that in case of stationary machinery, the basic safety failure area over the studied years pertained to loss of control over the machine, load or tool. On the other hand, in case of non-stationary machinery – the basic safety failure area covered: damage, rupture, cracking, falling, and breaking of a material factor.

At the same time, as a result of comparison in successive analysed years, the structure of shares of incidents that deviated from normal faultless operation, it was noted that both in case of stationary and non-stationary machinery, increased share was observed for such deviation / failure groups as: loss of control over the machine, load or tool, and slipping, stumbling, falling of a person; whereas a lower share was identified for such deviation / failure groups as: damage, rupture, cracking, breaking of a material factor, movement of the body involving physical effort, and discharge, leak or emission of harmful substances.

Furthermore, as a result of our studies, tendencies were identified in variations in shares of particular incidents that deviated from normal faultless operation for stationary and non-stationary machinery, in years 2005-2012 – Table 4.

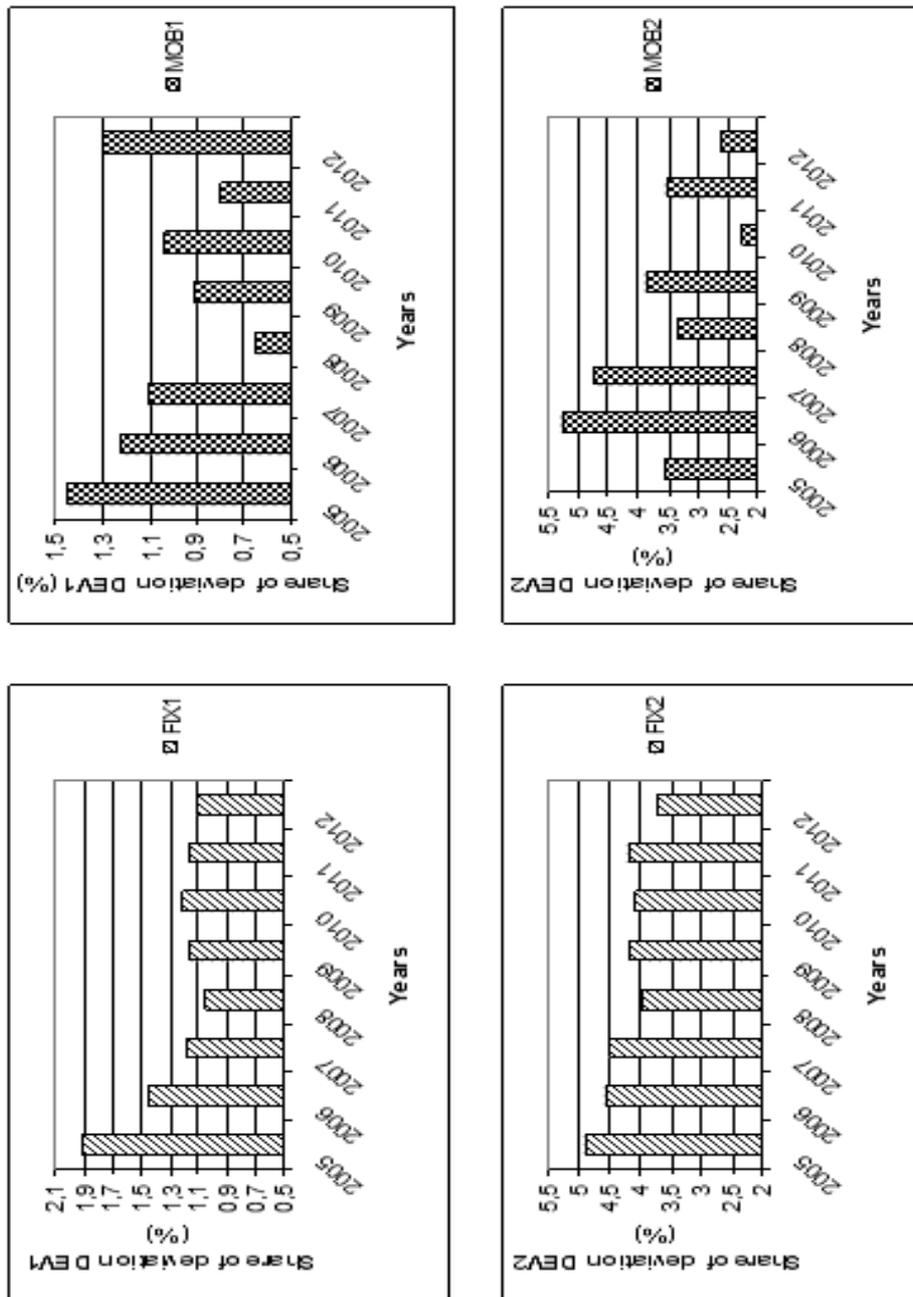


Fig.3. Share of deviations 1 and 2 for stationary machinery (FIX) and non-stationary machinery (MOB) in years 2005-2012 (in %)
 Source: our own work based upon annual GUS reports concerning accidents at work [8]

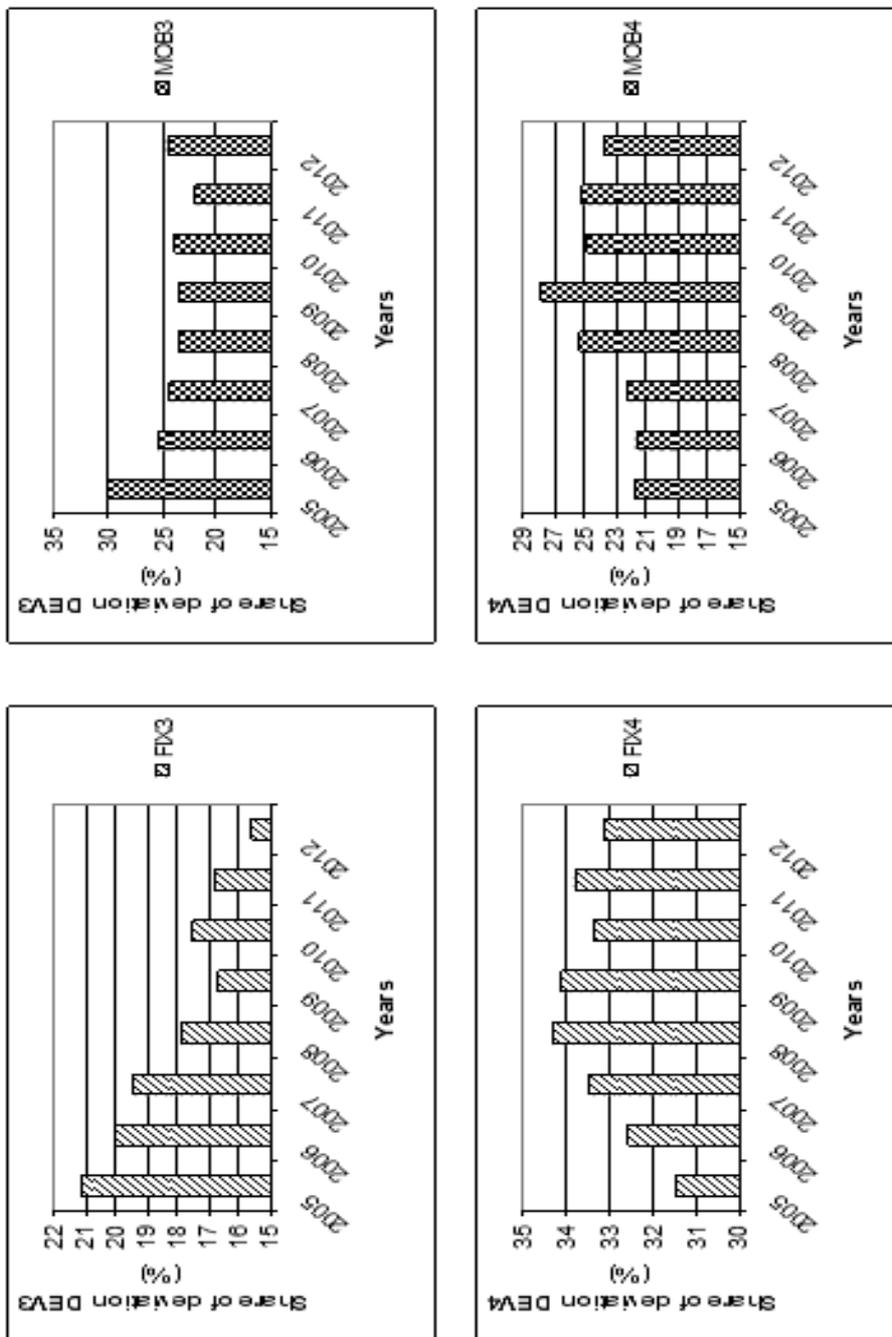


Fig.4. Share of deviations 3 and 4 for stationary machinery (FIX) and non-stationary machinery (MOB) in years 2005-2012 (in %) Source: our own work based upon annual GUS reports concerning accidents at work [8]

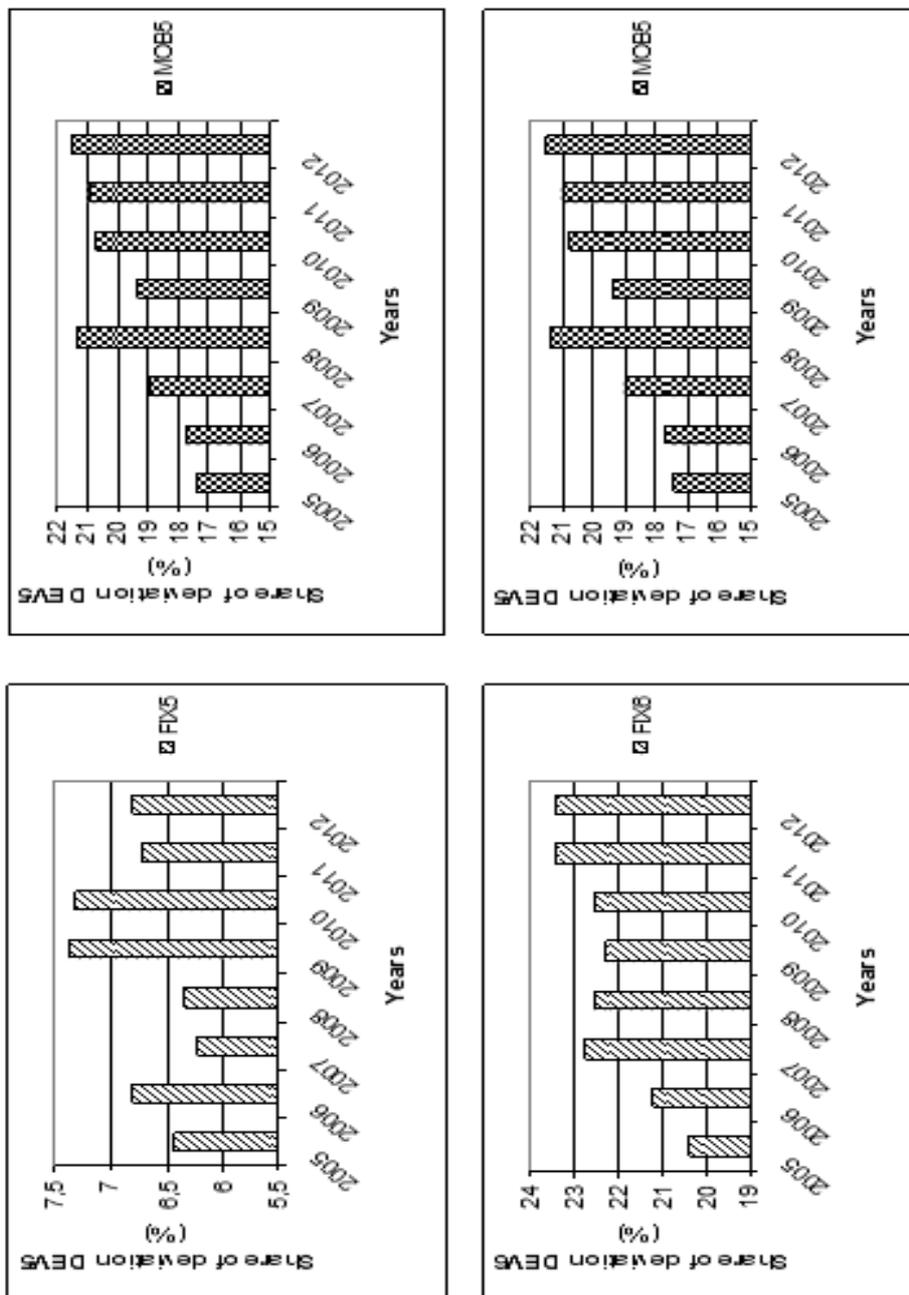


Fig.5. Share of deviations 5 and 6 for stationary machinery (FIX) and non-stationary machinery (MOB) in years 2005-2012 (in %)
 Source: our own work based upon annual GUS reports concerning accidents at work [8].

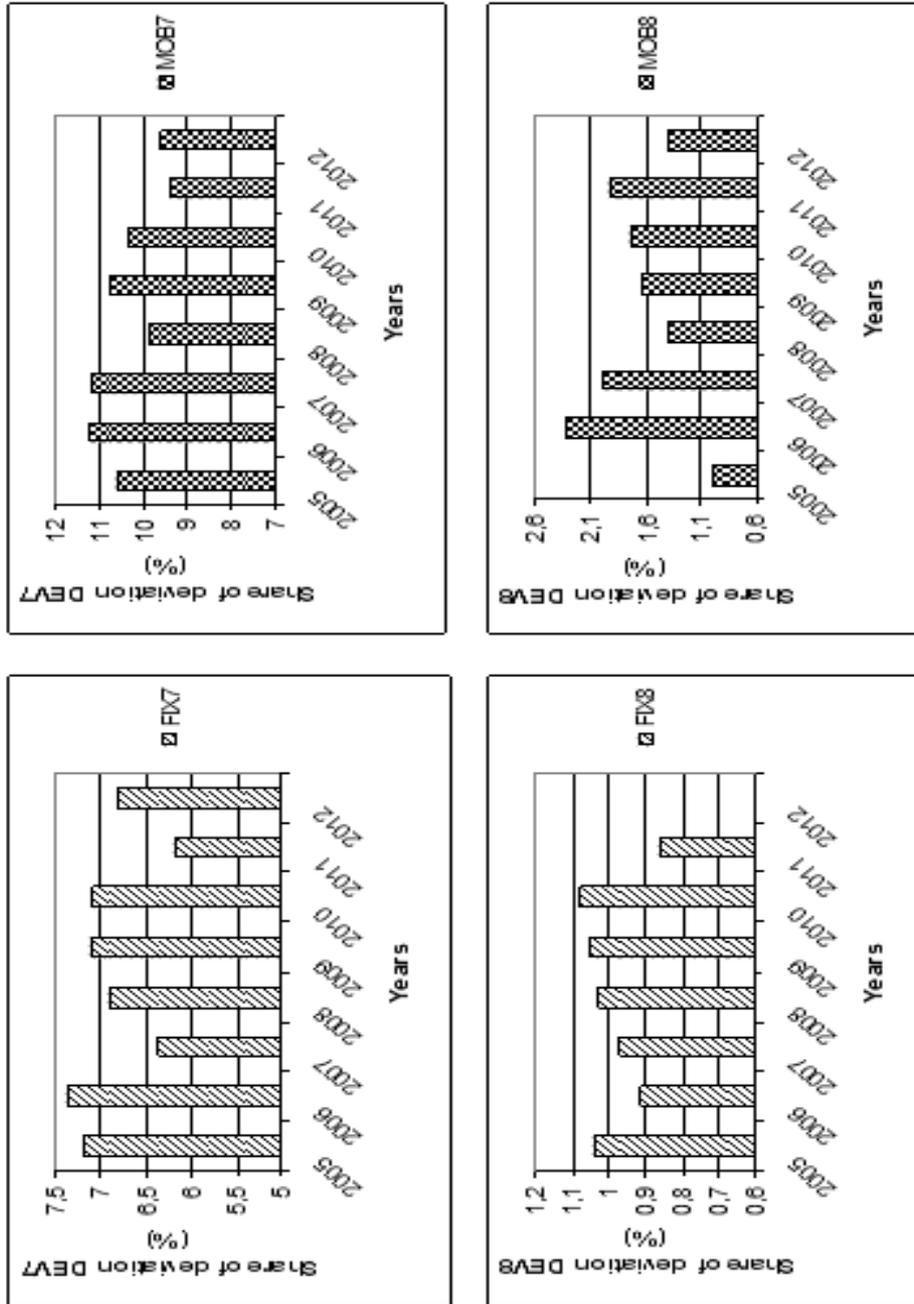


Fig. 6. Share of deviations 7 and 8 for stationary machinery (FIX) and non-stationary machinery (MOB) in years 2005-2012 (in %)
 Source: our own work based upon annual GUS reports concerning accidents at work [8].

Tab. 4. Juxtaposition of results of comparative analysis for tendencies in variations in shares of incidents that deviated from normal faultless operation, for stationary - fixed and non-stationary – portable or mobile machinery

	Machines ad equipment – fixed	Machines and equipment – portable or mobile
DEV1	Decrease from 1.91 to 1.16 %	Decrease from 1.45 to 0.80 %
DEV2	Decrease from 4.90 to 4.20 %	Decrease from 3.57 to 3.52 %
DEV3	Decrease from 21.11 to 16.80 %	Decrease from 29.91 to 21.86 %
DEV4	Increase from 31.48 to 33.80 %	Increase from 21.76 to 25.14 %
DEV5	Increase from 6.43 to 6.71 %	Increase from 17.41 to 20.98 %
DEV6	Increase from 20.38 to 23.40 %	Decrease from 10.27 to 9.85 %
DEV7	Decrease from 7.19 to 6.18 %	Decrease from 10.6 to 9.37 %
DEV8	Decrease from 1.04 to 0.86 %	Increase from 1.00 to 1.92 %

DEV1- Deviation due to electrical problems, explosion, fire, DEV2- Deviation by overflow, overturn, leak, flow, vaporization, emission, DEV3- Breakage, bursting, splitting, fall, collapse of Material Agent, DEV4- Loss of control of machine, means of transport or handling equipment, handheld tool, object, DEV5- Slipping, stumbling, fall of persons, DEV6- Body movement without any physical stress, DEV7- Body movement under or with physical stress, DEV8- Shock, fright, violence, aggression, threat, presence, DEV9- Other deviations

Source: our own work

By comparing these tendencies, it can basically be observed that the analysed machinery groups differed from each other only in terms of deviation that comprised movement of the body without physical effort. In case of deviations / failures connected with the technical object, a falling tendency was observed both for the first and the second machinery group; whereas in case of deviations / failures connected with a human being – a rising tendency was observed.

Thus, broadly speaking, the results of our statistical data studies as above-presented point towards an increasing failure rate in the area of the human factor; and towards decreasing failure rate – in the area of the technical object. Therefore, preventive actions taken in the area of safety reliability improvement should be oriented towards improving human reliability rate in the system of work.

Bibliography

1. Dyrektywa 2009/104/WE Parlamentu Europejskiego i Rady z dnia 16 września 2009 r. dotycząca minimalnych wymagań w dziedzinie bezpieczeństwa i higieny użytkownika sprzętu roboczego przez pracowników podczas pracy, Dziennik Urzędowy Unii Europejskiej, L 260/5, 3.10.2009.
2. Tabor J.: Quality of the material factor and the Safety of Work, Charter 2, [in:] Production Improvement. Monograph. Editing and Scientific Elaboration: Stanisław Borkowski, Manuela Konstanciak, Publish. TRIPSOFT, Trnava 2011.
3. Dyrektywa 2006/42/WE Parlamentu Europejskiego i Rady z dnia 17 maja 2006 r. w sprawie maszyn, Dziennik Urzędowy Unii Europejskiej, L 157/24, 9.06.2006.
4. Szopa T.: Niezawodność i bezpieczeństwo. Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2009.

5. Oziemski S.: Efektywność eksploatacji maszyn. Podstawy techniczno-ekonomiczne. Biblioteka Problemów Eksploatacji, Instytut Technologii Eksploatacji, Radom 1999.
6. Będkowski L., Dąbrowski T.: Podstawy eksploatacji. Część II. Podstawy niezawodności eksploatacyjnej. Wydaw. Wojskowej Akademii Technicznej, Warszawa 2006.
7. Legutko S.: Eksploatacja maszyn. Wydaw. Politechniki Poznańskiej, Poznań 2007.
8. Wypadki przy pracy w latach 2005-2012. Informacje i opracowania statystyczne, Wydaw. GUS, Warszawa 2006-2013, [publikacje dostępne na http://www.stat.gov.pl/gus/praca_ludnosc_PLK_HTML.htm].
9. Rozporządzenie Ministra Gospodarki i Pracy z dnia 8 grudnia 2004 r. w sprawie statystycznej karty wypadku przy pracy (Dz. U. Nr 269, poz. 2672).
10. Rozporządzenie Ministra Pracy i Polityki Społecznej z dnia 8 listopada 2010 r. w sprawie statystycznej karty wypadku przy pracy (Dz. U. Nr 218, poz. 1440).

Dr inż. Joanna Tabor
Zakład Systemów Technicznych i Bezpieczeństwa Pracy
Politechnika Częstochowska
42-201 Częstochowa, ul. J.H. Dąbrowskiego 69
tel. (34) 32-50-216, 609-460-906
e-mail: joanna.tabor@interia.pl